DECLARATION

I, the undersigned, of 2-12, Nakazaki 2-chome, Kita-ku, Osaka, Japan, hereby certify that I am well acquainted with the English and Japanese languages, that I am an experienced translator for patent matter, and that the attached document is a true English translation of

Japanese Patent Application No. 10-154689

that was filed in Japanese.

I declare that all statements made herein of may own knowledge are true, that all statements on information and belief are believed to be true, and that these statements were made with the knowledge that willful statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Signature:

Y. Iwasaka

Yoshiharu Iwasaka

Dated: September 12, 2003

[Name of the Document] SPECIFICATION

[Title of the Invention] BIPOLAR TRANSISTOR

[Claims]

[Claim 1] A bipolar transistor comprising an emitter layer doped with an impurity of a first conductivity type, a base layer doped with an impurity of a second conductivity type, and a collector layer doped with the impurity of the first conductivity type, characterised in that

the bipolar transistor has a high-concentration doped layer provided in a region of the emitter layer in proximity to the base layer and doped with the impurity of the first conductivity type at a higher concentration than in the emitter layer.

[Claim 2] The bipolar transistor according to claim 1, characterised in that

the high-concentration doped layer is a δ-doped layer having a thickness of 10 nm or less.

[Claim 3] The bipolar transistor according to claim 1 or 2, characterised in that

the concentration of carriers of the first conductivity type in the high-concentration doped layer is 1 x 10^{19} cm^{3} or more.

[Claim 4] The bipolar transistor according to any one of claims 1 to 3, characterised in that

the concentration of carriers of the first conductivity type in the high-concentration doped layer is ten or more times higher than the concentration of the carriers of the first conductivity type in the emitter layer.

[Claim 5] The bipolar transistor according to any one of

claims 1 to 4, characterised in that

the high-concentration doped layer is adjacent to a depletion region formed at an emitter/base junction portion.

[Claim 6] The bipolar transistor according to any one of claims 1 to 5, characterised in that

the concentration of carriers of the second conductivity type in the base layer is higher than the concentration of carriers of the first conductivity type in the emitter layer.

[Claim 7] The bipolar transistor according to any one of claims 1 to 6, characterised in that

the emitter layer and the base layer are composed of two types of semiconductor materials having different band gaps so that the semiconductor material composing the emitter layer has the wider band gap, and

the bipolar transistor has a heterojunction portion between the emitter layer and the base layer.

[Claim 8] The bipolar transistor according to claim 7, characterised in that

the base layer is strained.

[Claim 9] The bipolar transistor according to claim 7 or 8, characterised in that

the band gap of the base layer grades decreasingly from a region thereof closer to the emitter layer toward a region thereof closer to the collector layer.

[Claim 10] The bipolar transistor according to any one of claims 7 to 9, characterised in that

the base layer is composed of a semiconductor containing

at least silicon an germanium.

[Detailed Description of the Invention]

[Technical Field to which the Invention Belongs]

The present invention relates to a bipolar transistor and particularly relates to measures for suppressing reverse injection of carriers from a base into a region of an emitter adjacent an emitter/base junction in a heterojunction bipolar transistor.

[Prior Art]

Because of its excellent RF characteristics, a bipolar transistor has conventionally been used as an active device operable in the microwave/milliwave bands. In particular, most vigorous research and development has been directed to a heterojunction bipolar transistor (HBT) using a III-V compound semiconductor such as GaAs. In recent years, attention has been focused on a HBT using a SiGe material, which is a IV-IV compound material that can be fabricated on a low-cost silicon substrate.

The representative structures for implementing higher-speed SiGe HBTs are the following two types of HBTs: i.e., a HBT which comprises a collector layer of Si, a base layer of SiGe, and an emitter layer of Si and in which a Ge composition ratio in the SiGe base layer is increased gradually from a region in contact with the Si emitter layer toward a region in contact with the Si collector layer to provide a graded composition base layer (L. Harame et al., "Optimization of SiGe HBT Technology for High Speed Analog and Mixed-Signal Applications," IEDM Tech. Dig. 1993, p.71); and a HBT which comprises a collector layer of Si, a base layer of SiGe, and an emitter layer of Si and in which the SiGe base

layer has an extremely reduced thickness, an increased Ge composition ratio, and an increased doping concentration to provide a uniform composition base layer (A. Schuppen et al., "Enhanced SiGe Heterojunction Bipolar Transistors with 160 GHz-fmax," IEDM Tech. Dig. 1995, p.743.).

Figure 8 is a band diagram of the former heterojunction bipolar transistor having the graded composition base layer out of the two types of HBTs. As shown in the drawing, in the heterojunction bipolar transistor having the graded composition base layer, an electric field induced by the graded composition causes carriers injected into the SiGe base layer to drift in the SiGe base layer toward the collector layer. Since the travelling of the carriers caused by the drift electric field is at a higher speed than the travelling thereof caused by diffusion, a base transit time is reduced and excellent RF characteristics are obtained.

Figure 9 is a band diagram of the latter heterojunction bipolar transistor having the uniform composition base structure out of the two types of HBTs. As shown in the drawing, in the heterojunction bipolar transistor having the uniform composition base layer, the base layer is extremely thinned to reduce the base transit time and provide excellent RF characteristics. In this case, the thinning of the base layer incurs the risk of increasing the base resistance, and therefore the base layer is doped with a high-concentration impurity to lower the base resistance. In addition, SiGe having a high Ge composition ratio is used in the base layer to prevent reverse injection of carriers from the base layer doped with the high-concentration impurity into the emitter,

so that a heterojunction barrier formed between the SiGe base layer and the Si emitter layer is increased. In this case also, excellent RF characteristics are obtained. In particular, the concentration of carriers in the base layer is increased to reduce the base resistance and thereby increase a maximum oscillation frequency.

[Problems that the Invention is to solve]

In the conventional HBT having the graded composition base shown in Figure 8, however, it is required to increase the gradient of the composition ratio in order to increase the intensity of the drift electric field induced by the graded composition. In short, it is required to reduce the Ge composition ratio in a region of the base layer closer to the emitter layer and raise the Ge composition ratio in a region of the base layer closer to the collector layer. To satisfy the requirement, the region of the base layer closer to the emitter layer normally has a Si composition without containing Ge. In this case, the base/emitter PN junction forms a silicon/silicon homojunction. In increasing the maximum oscillation frequency f_{max} of the HBT, it is effective to reduce the base resistance as represented by the following equation (1).

[Equation 1]

$$f_{max} = \sqrt{\frac{f_T}{8\pi \cdot R_B \cdot C_{BC}}}$$

f_T: current gain cutoff frequency

R_B: base resistance

C_{BC}: base/collector junction capacitance

If a base doping concentration is increased to reduce the base resistance, however, the quantity of holes injected from the base layer into the emitter layer is naturally increased.

In the case where the emitter/base junction forms a homojunction or where the emitter/base junction forms a heterojunction but has a nearly Si composition at the end of the base, the quantity of carriers reversely injected into the emitter is increased because the base layer has no heterojunction barrier or, if any, an extremely low heterojunction barrier. Accordingly, the current amplification factor β is not increased.

The fact that the current amplification factor β is not increased can also be derived from the relationship represented by the following equation (2), which is established among the current amplification factor β, the band discontinuity value ΔEv of a valence band at the emitter/base junction, and a doping concentration N_B in the base layer.

[Equation 2]

$$\beta = \frac{J_n}{J_p} = \left(\frac{N_E}{N_B}\right) \cdot \left(\frac{V_n}{V_p}\right) \cdot exp\left(\frac{\Delta E_V}{kT}\right)$$

N_E: doping concentration in emitter layer

N_B: doping concentration in base layer

V_n: speed of electron diffusion in base layer

V_p: speed of hole diffusion in emitter layer

k: Boltzmann's constant

T: absolute temperature

In the case of using such a graded composition base, it becomes

therefore possible to reduce the base transit time and improve the current gain cutoff frequency f_T. However, the increase of the maximum oscillation frequency f_{max} cannot eventually be expected since the concentration of carriers in the base layer cannot be increased.

On the other hand, the conventional structure using the uniform composition base shown in Figure 9 can suppress reverse injection of carriers from the base layer because a high heterojunction barrier is formed between the base layer having a high Ge composition ratio and an emitter layer. In order to reduce the base transit time, the base layer is required to be extremely thinned. However, the base layer and the base resistance have a trade-off relationship that the base resistance increases as the base layer is decreased in thickness. The doping concentration in the base layer is required to be further increased in order to increase the maximum oscillation frequency f_{max}. In this case, it is required to further increase the Ge composition ratio in the base layer, which causes a problem of a critical film thickness at which a dislocation occurs in the base layer due to the difference in lattice constant between the emitter layer and the base layer.

Therefore, though it is possible to provide a heterojunction in the emitter/base junction and enhance, to a certain degree, the function of suppressing reverse injection of carriers from the base into the emitter through the formation of a heterojunction barrier, there is a limit to the improvement of the RF characteristics of a bipolar transistor in such a manner.

The present invention has its object of providing a bipolar transistor wherein restrictions on increase of a base doping concentration are relaxed with the provision of a region having the function of suppressing reverse injection of carriers from the base layer into the emitter layer irrespective of a heterojunction barrier formed at the emitter/base junction and wherein the current amplification factor can be improved even when the base doping concentration is increased to increase the maximum oscillation frequency f_{max} by relaxing the restrictions on the increase of the base doping concentration.

[Means for Solving the Problems]

To attain the above object, the present invention is directed to providing, in an emitter layer of a bipolar transistor, a high-concentration doped layer for effectively enhancing the function of suppressing reverse injection of carriers from a base layer into the emitter layer. Specifically, means for a bipolar transistor are provided as follows.

The bipolar transistor according to the present invention comprises an emitter layer doped with an impurity of a first conductivity type, a base layer doped with an impurity of a second conductivity type, and a collector layer doped with the impurity of the first conductivity type, and has a high-concentration doped layer provided in a region of the emitter layer in proximity to the base layer and doped with the impurity of the first conductivity type at a higher concentration than in the emitter layer.

This produces not only a barrier induced by a discontinued valence band at the emitter/base junction but also band modulation

induced by the high-concentration doped layer, so that the carriers in the base layer are inhibited from being reversely injected into the emitter layer. By suppressing reverse injection of carriers, therefore, it becomes possible to improve the current amplification factor as well as the RF characteristics such as a maximum oscillation frequency f_{max} even if the doping concentration of carriers in the base layer is increased.

In the bipolar transistor, the high-concentration doped layer is preferably a δ-doped layer having a thickness of 10 nm or less.

In the bipolar transistor, the concentration of carriers of the first conductivity type in the high-concentration doped layer is preferably 1×10^{19} cm^{3} or more.

In the bipolar transistor, the concentration of carriers of the first conductivity type in the high-concentration doped layer is preferably ten or more times higher than the concentration of the carriers of the first conductivity type in the emitter layer.

In the bipolar transistor, the high-concentration doped layer is preferably adjacent to a depletion region formed at an emitter/base junction portion.

With this arrangement, there can maximally be performed the function of suppressing reverse injection of carriers from the base to the emitter.

In the bipolar transistor, the concentration of carriers of the second conductivity type in the base layer is preferably higher than the concentration of carriers of the first conductivity type in the emitter layer.

Preferably, in the bipolar transistor, the emitter layer

and the base layer are composed of two types of semiconductor materials having different band gaps so that the semiconductor material composing the emitter layer has the wider band gap, and the bipolar transistor has a heterojunction portion between the emitter layer and the base layer.

With this arrangement, the function of suppressing reverse injection of carriers from the base layer is further enhanced by using a high barrier at the heterojunction portion.

In the bipolar transistor having the heterojunction portion, the base layer is preferably strained.

With this arrangement, the strained base layer achieves a particularly high effect when the difference in lattice constant between the emitter layer and the base layer is large.

In this case, it is preferable that the band gap of the base layer grades decreasingly from a region thereof closer to the emitter layer toward a region thereof closer to the collector layer.

With this arrangement, the travelling speed of carriers in the base layer is determined by a drift velocity, not by a diffusion speed, so that the base transit time is reduced and a current gain cutoff frequency f_T is increased. In addition, the high-concentration doped layer suppresses reverse junction of carriers from the base layer into the emitter layer irrespective of the band discontinuity value reduced by the provision of the graded composition base. Moreover, reduction in base resistance attributable to higher-concentration base doping or increase in thickness of the base layer can also be achieved, which increases a maximum oscillation frequency f_{max}.

In the bipolar transistor having the heterojunction portion, the emitter layer is preferably composed of a semiconductor containing silicon and the base layer is preferably composed of a semiconductor containing at least silicon an germanium.

With this arrangement, a heterojunction bipolar transistor excellent in RF characteristics can be obtained while using inexpensive semiconductor materials.

[Embodiment of the Invention]

The present embodiment relates to a heterojunction bipolar transistor characterised in that a heterojunction barrier height (barrier height) is effectively increased by providing, in a region of an emitter adjacent an emitter/base junction, a δ-doped layer having an extremely high impurity concentration to suppress reverse injection of carriers from a base layer and thereby improve the current gain and RF characteristics of the heterojunction bipolar transistor.

Figure 1 shows a structure of an NPN heterojunction bipolar transistor having the δ-doped layer provided in the emitter layer according to the present embodiment. As shown in the drawing, a high-concentration n-type Si subcollector layer 2, an n-type Si collector layer 3, a high-concentration p-type SiGe base layer 4, an n-type Si emitter layer 5, and a high-concentration n-type Si emitter contact layer 6 are stacked sequentially on a Si substrate 1 by MBE. A collector electrode 20, a base electrode 21 and an emitter electrode 22 are disposed on the Si subcollector layer 2, the SiGe base layer 4 and the Si emitter contact layer 6, respectively.

The thickness of the high-concentration n-type Si subcollector layer 2 is approximately 500 nm and the impurity concentration in the Si subcollector 2 is approximately 2 x 10^{19} cm^{-3}. The thickness of the n-type Si collector layer 3 is approximately 650 nm and the impurity concentration in the Si collector layer 3 is approximately 1 x 10^{17} cm^{-3}. The thickness of the high-concentration p-type SiGe base layer 4 is approximately 50 nm and the impurity concentration in the SiGe base layer 4 is approximately 1 x 10^{19} cm^{-3}. The thickness of the n-type Si emitter layer 5 is approximately 100 nm and the impurity concentration in the Si emitter layer 5 is approximately 2 x 10^{18} cm^{-3}. The thickness of the high-concentration n-type Si emitter contact layer 6 is approximately 50 nm and the impurity concentration in the Si emitter contact layer 6 is approximately 2 x 10^{19} cm^{-3}. These layers have been formed sequentially by MBE.

A δ-doped Si layer 10 heavily doped with an n-type impurity is provided in a region of the n-type emitter layer 5 adjacent the emitter/base junction portion. The thickness of the δ-doped Si layer 10 is approximately 5 nm and the impurity concentration therein is approximately 1 x 10^{20} cm^{-3}. The δ-doped Si layer 10 is disposed in the region of the emitter at a distance of approximately 40 nm from the emitter/base junction portion. The SiGe base layer 4 has a graded composition base structure in which a Ge composition ratio increases substantially continually in the range of 0% to 30% from a region closer to the Si emitter layer 5 toward a region closer to the Si collector layer 3. Boron is used as the p-type dopant and antimony is used as the n-type dopant.

Figure 2 is a band diagram of the NPN heterojunction bipolar transistor according to the present embodiment, in which the δ-doped Si layer is provided in the emitter layer. Figure 3 is a band diagram of the conventional NPN heterojunction bipolar transistor, in which the δ-doped Si layer is not provided in the Si emitter layer.

As can be seen from Figures 2 and 3, when the δ-doped Si layer 10 heavily doped with an n-type impurity is provided in the region of the emitter adjacent the emitter/base junction, the band is modulated by the δ-doped Si layer 10 and a potential barrier against holes is formed. From the viewpoint of holes in the SiGe base layer 4, the provision of the δ-doped Si layer 10 has increased an effective barrier height. Consequently, the reverse injection of the holes into the emitter is suppressed even when the hole concentration in the SiGe base layer 4 is increased, which provides a sufficient current gain. As a result, there can be implemented a HBT which is low in base resistance and extremely high in maximum oscillation frequency f_{max}.

The height of the potential barrier enhanced by the δ-doped Si layer 10 is varied by a doping concentration in the δ-doped Si layer 10, a doping concentration in a region of the Si emitter layer 5 on the periphery of the δ-doped Si layer 10, and an impurity profile in the δ-doped Si layer 10.

Figure 4 is a graph showing variations in barrier height plotted against the carrier concentration in the δ-doped Si layer. It is to be noted that Figure 4 is a graph obtained when the carrier concentration in the Si emitter layer is 1×10^{18} cm^{-3}. In the

present embodiment, the carrier concentration in the Si emitter layer 5 is 2×10^{18} cm^{-3}, while the carrier concentration in the δ-doped Si layer 10 is 1×10^{20} cm^{-3}, so that the carrier concentration ratio therebetween is 1:50. Thus, the δ-doped Si layer 10 according to the present embodiment has enhanced the barrier height by approximately 100 meV, which corresponds to a barrier height when the carrier concentration in the δ-doped Si layer is 5×10^{19} cm^{-3} in Figure 4 (i.e., when the carrier concentration ratio therebetween is 1:50).

For the effect of the present invention to be exerted more effectively, the carrier concentration in the δ-doped Si layer 10 is preferably 1×10^{19} cm^{3} or higher. In addition, the increment of the barrier height caused by the δ-doped Si layer 10 is preferably by a factor of 10 or more. It will be understood that the barrier height is higher by 50 meV when the carrier concentration in the δ-doped Si layer 10 is ten times as high as the carrier concentration in the Si emitter layer 5. Hence, the carrier concentration in the δ-doped Si layer 10 is preferably ten or more times higher than the carrier concentration in the Si emitter layer 5.

Further, as can be seen from Figure 2, if the carrier concentration in the SiGe base layer 4 is higher than the carrier concentration in the Si emitter layer 5, this desirably makes the barrier against reverse injection of holes higher.

Figure 5 is a view showing the relationship (represented by the solid curve) between the current amplification factor β and a collector current in the NPN heterojunction bipolar transistor in which the δ-doped Si layer 10 is provided in the emitter layer

according to the present embodiment and the relationship (represented by the dashed curve) between the current amplification factor β and a collector current in the conventional NPN heterojunction bipolar transistor in which the δ-doped Si layer is not provided in the emitter layer. As shown in the drawing, the current amplification factor β has been improved in the present embodiment with the provision of the δ-doped Si layer 10 in the Si emitter layer 5. The difference in current amplification factor β between the two heterojunction bipolar transistors is particularly conspicuous in a region with a large collector current. Since a high current amplification factor β is obtained in the heterojunction bipolar transistor according to the present embodiment even with such a large collector current, the maximum value f_{Tmax} of the current cutoff frequency is increased by about 25% as compared with the maximum value f_{Tmax} in the heterojunction bipolar transistor without a δ-doped Si layer.

If the Ge composition ratio in the SiGe base layer 4 is increased, a dislocation may occur depending on the critical film thickness of SiGe. The respective critical film thicknesses for $Si_{0.2}Ge_{0.8}$, $Si_{0.3}Ge_{0.7}$ and $Si_{0.4}Ge_{0.6}$ when the underlie is Si are approximately 180 nm, 56 nm and 25 nm.

In increasing the critical film thickness, it is effective to use $Si_{1-x-y}Ge_xC_y$ to compose the base layer. By adjusting the Ge composition to 40% or more and adding a slight amount of C (on the order of several percentage) thereto, a strained lattice can be alleviated without greatly varying the magnitude of the band discontinuity value ΔEv of the emitter/base junction, which

increases the critical film thickness of the base layer. By thus composing the base layer of $Si_{1-x-y}Ge_xC_y$, a larger band discontinuity value ΔEv can be obtained without exceeding the critical film thickness.

Next, a description will be given to the effect of improving the RF characteristics of the HBT in which the δ-doped Si layer 10 is provided in the Si emitter layer 5 to enhance the effective barrier height and the SiGe base layer 4 is formed in a graded composition.

Figure 6 shows the result of calculating the degree to which the base transit time of carriers has been reduced (base transit time reduction factor) in the HBT in which the barrier height has been enhanced by the δ-doped Si layer 10 and the Ge composition ratio in the SiGe base layer 4 has been graded as shown in Figure 8, compared with the base transit time in the conventional HBT using the uniform composition base layer.

As will be seen from Figure 6, the base transit time is reduced in accordance with the gradient if a graded composition is given to the base layer having the same thickness as the conventional uniform composition base layer. When the gradient of the band gap is 300 meV in the graded composition, the base transit time is reduced to approximately 20% of the base transit time in the uniform composition base.

Figure 7 shows the result of calculating the degree to which the maximum oscillation frequency f_{max} (f_{max} increase factor) has been increased in the HBT in which the barrier height has been enhanced with the provision of the δ-doped Si layer 10 and the

graded composition base layer having an increased thickness for a reduced base resistance R_B is provided, compared with the maximum oscillation frequency f_{max} in the conventional HBT having the heavily doped uniform composition base layer. It is to be noted that the film thickness of the SiGe base layer 4 has been adjusted to provide a base transit time equal to the base transit time in the heavily doped uniform composition base layer of the conventional HBT. Since the base transit time is reduced by using the graded composition base layer, as shown in the drawing, the thickness of the base layer can be increased as the base gap gradient resulting from the graded composition is increased. As a result, the base resistance R_B is reduced and the maximum oscillation frequency f_{max} is increased. As shown in the drawing, the maximum oscillation frequency f_{max} when the band gap gradient resulting from the graded composition is 300 meV is 1.5 or more times higher than the maximum oscillation frequency in the uniform composition base.

From the foregoing, there have been derived the following effects that can be achieved by the heterojunction bipolar transistor (HBT) according to the present embodiment.

First, the provision of the δ-doped Si layer 10 for effectively enhancing the barrier height in the Si emitter layer achieves the same effect as achieved when the band discontinuity value ΔEv of the valence band at the emitter/base junction is substantially increased (see the equation (2)), resulting in an improved current amplification factor β. In other words, the provision of the δ-doped Si layer 10 for suppressing reverse injection of holes from the SiGe base layer 4 into the Si emitter

layer 5 reduces the current J_p shown in the equation (2) flowing from the base to the emitter and thereby improves the current amplification factor β. The effect is achievable whether the emitter/base junction is a heterojunction or not. Consequently, the same effect can also be achieved in a normal bipolar transistor other than a HBT.

Second, since the graded composition has been given to the SiGe base layer 4 and the δ-doped Si layer 10 is provided in the Si emitter layer 5, the Ge composition ratio in the SiGe base layer 4 varies such that the band gap in the SiGe base layer 4 gradually decreases from the region of the SiGe base layer 4 closer to the Si emitter layer 5 toward the region thereof closer to the Si collector layer 3, whereby the current gain cutoff frequency f_T is increased. As stated previously, if the base doping concentration is increased to lower the resistance of the uniform composition base layer in the conventional HBT, the quantity of holes reversely injected is increased so that a sufficient current gain is not obtained. By contrast, since the effective barrier height at the heterojunction portion is increased with the provision of the δ-doped Si layer 10 in the HBT according to the present invention, the effective barrier height is held sufficiently large even when the band discontinuity value of the heterojunction at the emitter/base junction is reduced with the provision of the SiGe graded composition base layer 4 and the base doping concentration is increased, which suppresses reverse injection of holes. Hence, there can be obtained the heavily doped base layer having a graded composition, which has conventionally been

unobtainable. As a result, the base transit time of electrons is reduced and the RF characteristics are improved.

Thirdly, since the base transit time is reduced by providing the graded composition base layer, the thickness of the base layer can be increased. As a result, the base resistance is reduced and the maximum oscillation frequency f_{max} is increased.

Fourthly, the fact that a sufficient current gain can be obtained even when the Ge composition ratio is low indicates that a dislocation caused by a thermal budget during the subsequent process step, which presents a problem when a high Ge composition ratio is used, can be suppressed. In the conventional HBT using the uniform composition base, it is required in doping the SiGe base layer with a high-concentration impurity to increase the Ge composition ratio in the SiGe base layer, so that the difference in lattice constant between the emitter layer and the Si base layer is increased disadvantageously to reduce the critical film thickness at which a dislocation is caused by the difference in lattice constant. However, if the effective barrier height is enhanced with the provision of the δ-doped Si layer 10, as in the present embodiment, satisfactory RF characteristics are achieved without increasing the Ge composition ratio in the SiGe base layer 4. The sufficient current gain obtainable with a low Ge composition ratio also achieves the effect of suppressing the occurrence of a dislocation due to the thermal budget during the subsequent process step, which presents a problem when a high Ge composition ratio is used, i.e., the effect of increasing the thermal budget. Briefly, this achieves the effect of providing

the device fabrication process with an increased margin as well as increased device reliability.

Fifthly, the temperature characteristic of the bipolar transistor can also be improved. Specifically, since the distribution of hole concentrations in the valence band of the SiGe layer 4 shifts downwardly at an increased temperature, the current amplification factor β of the bipolar transistor exhibits a tendency to lower as the temperature T increases. The tendency is particularly conspicuous when the band discontinuity value ΔEv is low. By contrast, the bipolar transistor according to the present invention provides a high current amplification factor β even at a high temperature owing to the function of suppressing reverse injection of holes performed by the δ-doped Si layer 10.

Thus, by providing the δ-doped Si layer 10 in the region of the emitter layer 5 adjacent the emitter/base junction of the heterojunction bipolar transistor, the current gain and RF characteristics of the heterojunction bipolar transistor can be improved.

For the δ-doped Si layer 10 to reliably perform the barrier function, the whole δ-doped Si layer 10 is preferably disposed externally of a depletion region formed between the emitter and the base at a maximum design voltage region (region depleted when a maximum design voltage is applied between the emitter and the base) and the δ-doped Si layer 10 is preferably adjacent to the depletion. This is because, if a part of the δ-doped Si layer 10 is located within the depletion region, the barrier height is reduced and the function of suppressing reverse injection of holes

may be degraded. Preferably, the δ-doped Si layer 10 in the Si emitter layer 5 is at a distance shorter than the diffusion length of hole from the SiGe base layer 4.

Although the present embodiment has described the improved characteristics of the heterojunction bipolar transistor as a single element, it will easily be appreciated that the HBT according to the present invention may also be used for the bipolar part of a BiCMOS device in which the bipolar transistor and a CMOS have been integrated.

Although the present embodiment has described the NPN SiGe HBT by way of example, it will easily be appreciated that the present invention is also applicable to a PNP bipolar transistor. Alternatively, the present invention may also be applied to a normal homojunction bipolar transistor other than the HBT and to a heterojunction bipolar transistor of III-V compound semiconductor layers, as stated previously.

[Effects of the Invention]

According to the present invention, a high-concentration doped layer doped with carriers at a higher concentration than in the emitter layer is provided in a region of the emitter adjacent the emitter/base junction, the band is modulated by the high-concentration doped layer and a potential barrier is formed, thereby effectively increasing the barrier height. Accordingly, reverse injection of the carriers from the base layer is suppressed, which increases the current amplification factor β. In addition, since the structural restrictions of the base layer are relaxed, the current gain cutoff frequency f_T and the maximum oscillation

frequency f_{max} can be improved.

Further, as compared with the conventional HBT using the uniform composition base, satisfactory RF characteristics are achieved, without using a high Ge composition ratio, due to the enhancement in effective barrier height with the provision of the high-concentration doped layer. Also, the occurrence of a dislocation due to the thermal budget during the subsequent process step, which presents a problem when a high Ge composition ratio is used, can be suppressed. This provides the device fabrication process with an increased margin as well as increased device reliability.

[Brief Description of the Drawings]

[Fig. 1]

A cross-sectional view of an NPN heterojunction bipolar transistor according to an embodiment, in which a δ-doped Si layer is provided in an emitter layer.

[Fig. 2]

A band diagram of the NPN heterojunction bipolar transistor according to the above embodiment, in which the δ-doped Si layer is provided in the emitter layer.

[Fig. 3]

A band diagram of an NPN heterojunction bipolar transistor in which the δ-doped Si layer is not provided in the emitter layer.

[Fig. 4]

A graph showing the relationship between a carrier concentration and an increase in effective barrier height in the δ-doped Si layer.

[Fig. 5]

A graph showing the relationship between a current amplification factor β and a collector current in the NPN heterojunction bipolar transistor in each of the cases where the δ-doped Si layer is provided and not provided in the emitter layer.

[Fig. 6]

A graph showing the result of calculating the degree to which a base transit time has been reduced in the HBT of the present invention having the barrier height enhanced by the δ-doped Si layer and a graded composition base layer, compared with the base transit time in a conventional HBT having a uniform composition base layer.

[Fig. 7]

A graph showing the result of calculating the degree to which a maximum oscillation frequency f_{max} has been increased in the HBT of the present invention having the barrier height enhanced by the δ-doped Si layer and the graded composition base layer with an increased film thickness, compared with a conventional HBT having the graded composition base layer.

[Fig. 8]

A cross-sectional view of a conventional SiGe NPN heterojunction bipolar transistor using the graded composition base layer.

[Fig. 9]

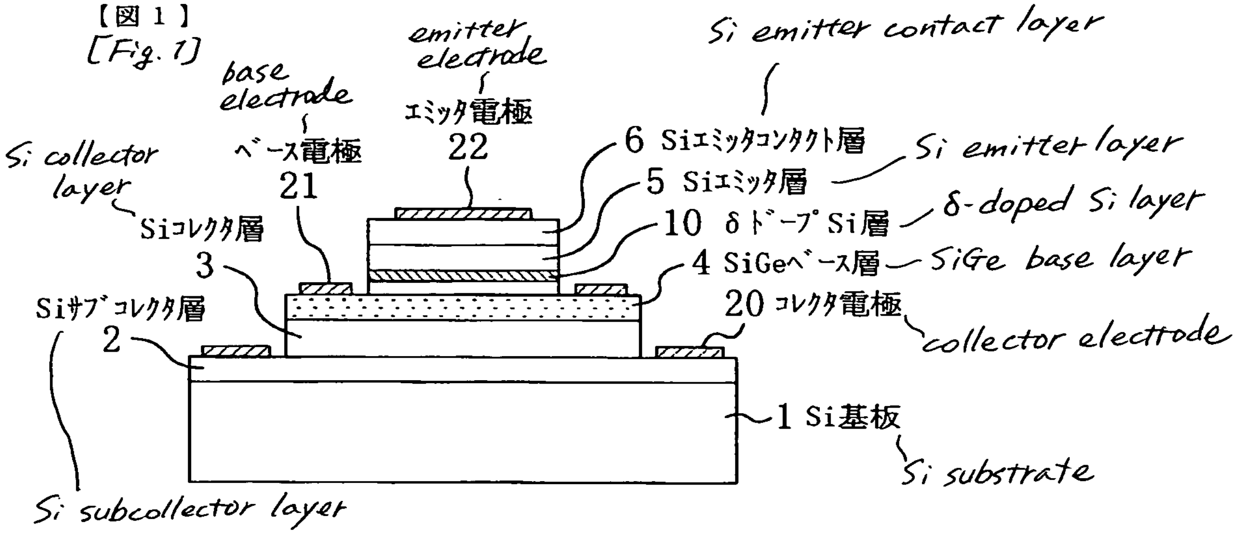
A band diagram of a conventional SiGe NPN heterojunction bipolar transistor using the uniform composition base layer.

[Explanation of References]

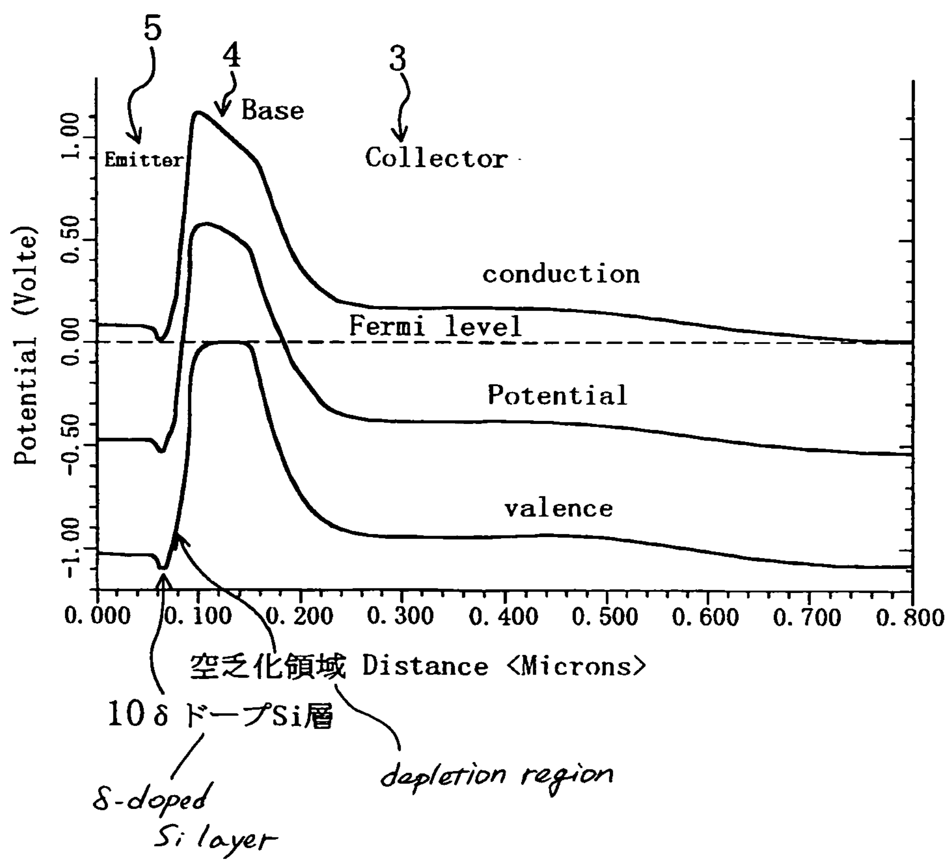
1	Si substrate
2	Si subcollector layer
3	Si collector layer
4	SiGe base layer
5	Si emitter layer
6	Si emitter contact layer
10	δ-doped Si layer
20	collector electrode
21	base electrode
22	emitter electrode

【書類名】　図面
[Name of the Document] DRAWINGS

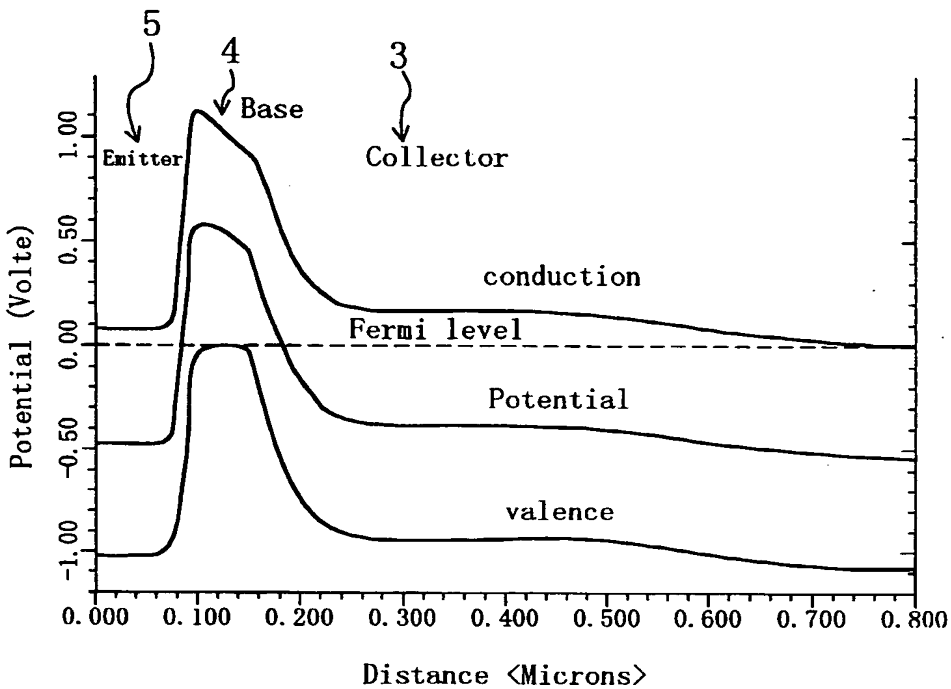
【図１】
[Fig. 1]



【図２】 [Fig. 2]



【図３】 [Fig. 3]


5
4
3
Base
Emitter
Collector
conduction
Fermi level
Potential
valence
Potential (Volte)
1.00
0.50
0.00
-0.50
-1.00
0.000
0.100
0.200
0.300
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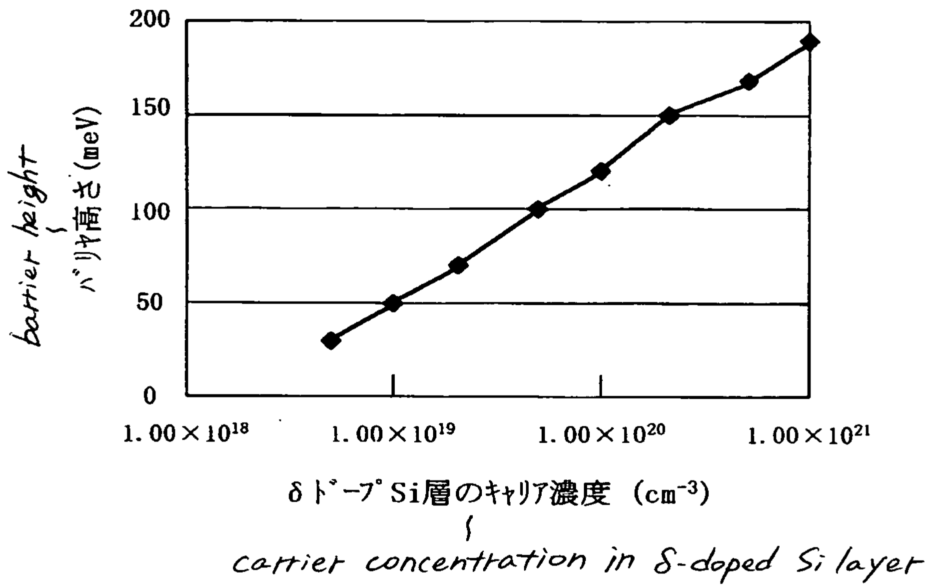
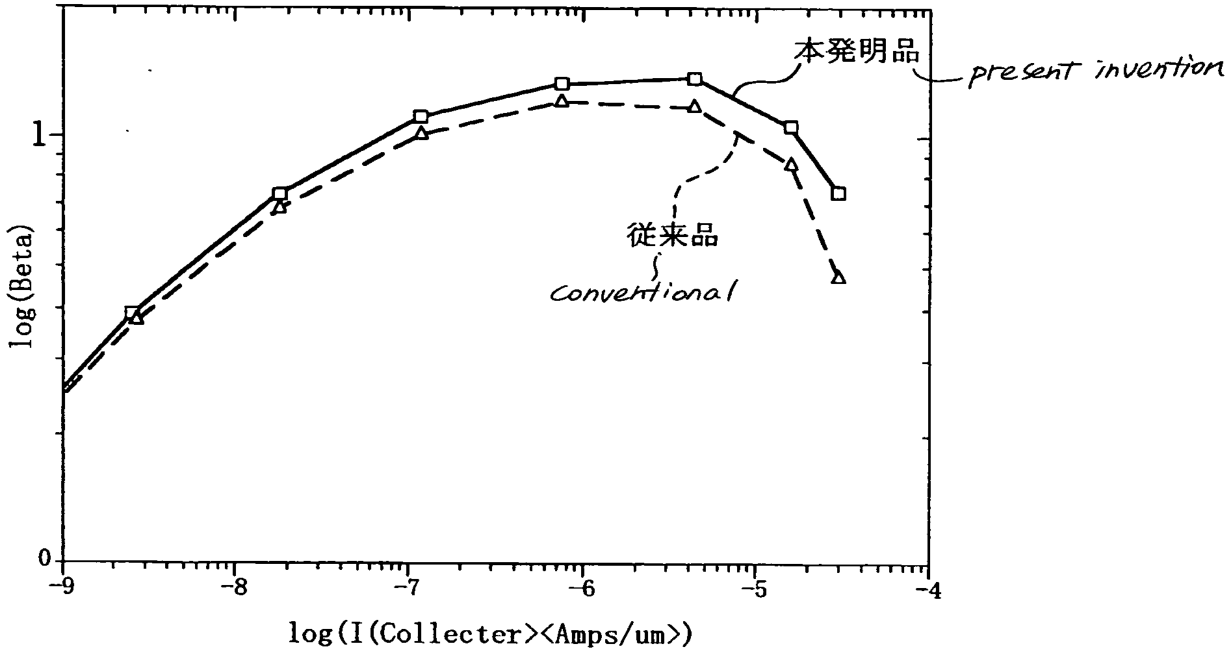
0.500
0.600
0.700
0.800
Distance <Microns>

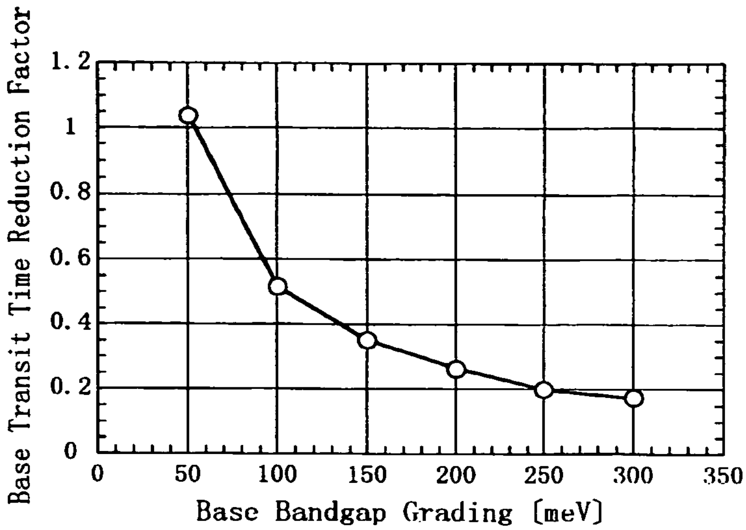
【図４】 [Fig. 4]


200
150
100
50
0
バリヤ高さ(meV)
barrier height
1.00×10^18
1.00×10^19
1.00×10^20
1.00×10^21
δドープSi層のキャリア濃度 (cm^-3)
carrier concentration in δ-doped Si layer

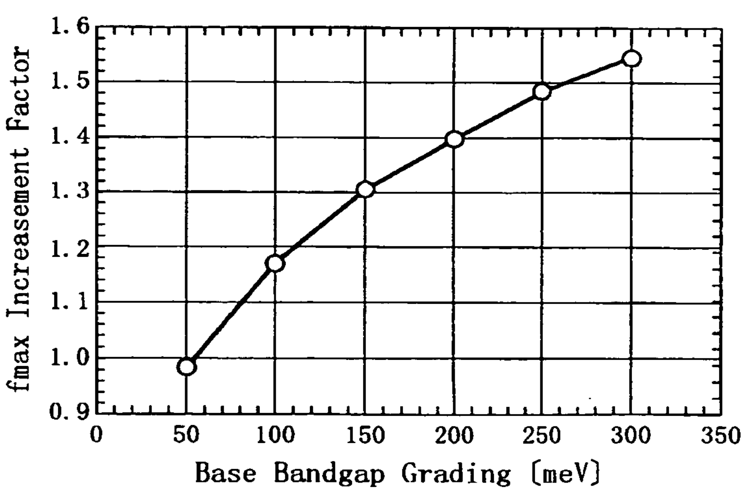
【図５】 [Fig. 5]


本発明品
present invention
従来品
conventional
1
0
log(Beta)
-9
-8
-7
-6
-5
-4
log(I(Collecter><Amps/um>)

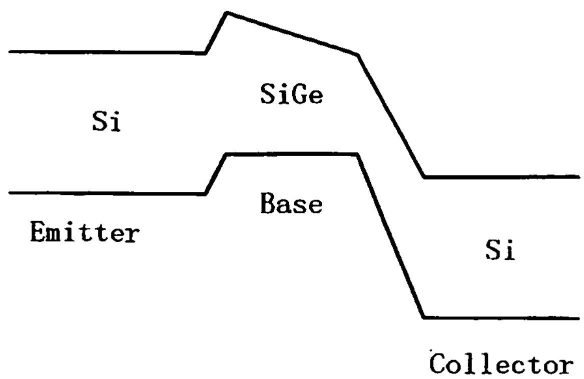
【図６】[Fig. 6]



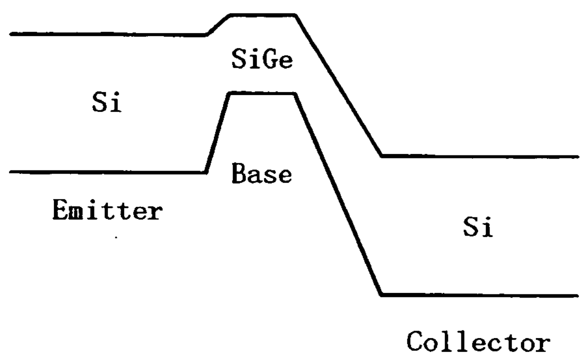
【図７】[Fig. 7]



【図８】[Fig. 8]



【図９】[Fig. 9]



[Name of the Document] ABSTRACT

[Abstract]

[Purpose] To provide a bipolar transistor having excellent RF characteristics such as a current amplification factor, a current gain cutoff frequency and a maximum oscillation frequency in a microwave band or the like.

[Solution] In a region of a Si emitter layer 5 adjacent the base/emitter junction of a heterojunction bipolar transistor, a δ-doped Si layer 10 locally high in concentration of carriers is provided. This enhances an effective barrier height and thereby suppresses reverse injection of the carriers from the SiGe base layer 4 into the Si emitter layer 5. As a result, the reverse injection of carriers is suppressed by the δ-doped Si layer 10 even when the base doping concentration is increased, which provides a satisfactory current amplification factor β and increases a maximum oscillation frequency f_{max}. In addition, even when a graded composition is given to the base layer to decrease the band discontinuity value at the emitter/base junction, a high maximum oscillation frequency can be obtained.

[Selected Figure] Figure 2